Final Report Printed by

California Department of Health Services
Environmental Health Investigations Branch
Oakland, California

BIOAEROSOLS
AND
GREEN-WASTE COMPOSTING
IN CALIFORNIA

June, 1999

Additional copies of this report are available from:

California Department of Health Services
Environmental Health Investigations Branch
1515 Clay Street, Suite 1700
Oakland, CA 94612
(510) 622-4500

AUTHORS AND ACKNOWLEDGMENTS

Authors

Sandra McNeel, Richard Kreutzer

California Department of Health Services
Division of Environmental and Occupational Disease Control
Environmental Health Investigations Branch
1515 Clay Street, Suite 1700
Oakland, California 94612

(510) 622-4500

Acknowledgments

We appreciate the assistance of Dr. Janet Macher (California Department of Health Services, Environmental Health Laboratory) in preparing the section on bioaerosol sampling. We also thank staff of the California Integrated Waste Management Board (particularly, Dorothy Rice, Diane Kihara, Julie Nauman, Caren Trgovcich) for their thoughtful review of the document, and their advice during its development. Thanks also to the Solid Waste Policy Committee of the California Conference of Directors of Environmental Health for their assistance in defining important issues. We also acknowledge the advice and support of Drs. Debra Gilliss and Raymond Neutra (California Department of Health Services) during the preparation of this report.

CONTENTS

Page

AUTHORS AND ACKNOWLEDGMENTS……………..………………………..ii

LIST OF TABLES…………………………………...……..…………………..v

LIST OF APPENDICES.……………………………………..…………….….…..vii

INTRODUCTION……………………………………………………….………...1

COMMON TYPES, SOURCES AND LEVELS OF BIOAEROSOL EXPOSURE IN COMMUNITIES

- ***Aspergillus fumigatus*………………………………………….……………..2**
- **Bacterial toxins……………………………….…………………….……...3**
- **Glucans……………………….……………………………………………4**
- **Thermophilic Actinomycetes………….……………………………….…….4**
- **Mycotoxins……………….…………………………………………….……..4**

HEALTH EFFECTS OF COMPOST BIOAEROSOLS

- ***Aspergillus fumigatus*……….…………………………………………….…….4**
- **Bacterial endotoxins……….…………………………………………………...6**
- **Glucans……………………………………………………………………………7**
- **Thermophilic Actinomycetes…………………………………………………..7**
- **Mycotoxins……………………………………………………………………...8**

FACTORS AFFECTING BIOAEROSOL EXPOSURE LEVELS

- **Design………………………………………………………………………8**
- **Siting……..……………………………………..……………………9**
- **Maintenance and Operations……………………………………………9**

EMPLOYEE PROTECTION………………………………………………..……10

WHAT ABOUT AIR MONITORING?………………………….………………10

SUMMARY…………………………………………...…………….…………..11

REFERENCES……………………………...…………………….…..….……12

TABLES………………………..………………………………………….……...17

APPENDICES…...……………………..……………………………………23

LIST OF TABLES

Page

Table 1 Bioaerosols of concern in yard-waste composting………………..17

Table 2 Seasonal counts of viable *Aspergillus fumigatus* particles in air in the Washington, D.C. metropolitan area during 19799-1980……………………………………………………….…18

Table 3 Distance from compost facilities to site where bioaerosol concentration equals background level……….……………………..19

Table 4 Examples of levels of airborne endotoxin in different environments…………………..………………………………….20

Table 5 Seasonal counts of thermophilic actinomycetes in air in the Washington, D.C. metropolitan are during 1979-1980…………..….21

Table 6 Buffer distance requirements for composting facilities in some states and Canadian provinces……………………………..22

LIST OF APPENDICES

Page

Appendix A - Bioaerosol monitoring…………………………………...…..A-1

Appendix B - Laboratories for bioaerosol testing…………………...…...B-1

BIOAEROSOLS AND GREEN-WASTE COMPOSTING IN CALIFORNIA

Environmental Health Investigations Branch
California Department of Health Services
June, 1999

Introduction -

This report is issued to complement information provided in the California Integrated Waste Management Board (CIWMB) Local Enforcement Agency (LEA) Advisory No. 6, December 16, 1993 and Technical Bulletin No.1, "Aspergillus, Aspergillosis, and Composting Operations in California". This report was prepared in response to the following situations:

- Entrepreneurs are planning and building more green-waste composting facilities to implement mandated solid waste diversion goals stated in the Integrated Waste Management Act of 1989. As of March 1998, there were 78 operational green-waste composting sites in California, (CIWMB, 1998).

- Residents are concerned about the potential health effects of *Aspergillus fumigatus* and other bioaerosols from composting facilities.

- LEA's and local government officials have increased responsibility for siting and declarations of safety under the California Environmental Quality Act due to revision of the Integrated Waste Management Board Composting Operations Regulatory Requirements in July, 1995.

A panel of international experts on bioaerosols, risk assessment and composting was recently assembled to consider whether bioaerosols associated with the operation of biosolids or solid waste composting facilities endanger the health and welfare of the general public and the environment (Millner, et al, 1994). This group did not find epidemiological evidence to support increased risk of allergic, asthmatic or acute or chronic respiratory disease in the general public at or around the several open air and one enclosed composting sites that were evaluated. The major basis for this conclusion was the fact that workers were regarded as the most exposed part of the community and where worker health was studied, no significant adverse health impacts were found. However, this group also recognized that data regarding levels of bioaerosol exposure are incomplete and that there may be subpopulations within the general population that are at increased risk due to preexisting medical/immunological or genetic conditions. It was also the consensus of the participants that additional research be conducted to more clearly define the nature and health impacts of bioaerosols from composting facilities compared with all other environmental sources.

Odor issues have been the most frequent public concern associated with composting operations in the past. Recently, some groups have posed questions about possible health effects associated with airborne dust from nearby composting sites. It is important to keep in mind that many different activities generate organic dusts. Handling cereal grains, wood, hay, cotton, wool and compost all produce airborne materials of animal, vegetable or microbial origin. This report examines the potential health effects of microbial constituents of airborne organic dust from composting of green-waste (i.e., yard trimmings). The term, "bioaerosols", as used in this report includes microbes such as bacteria and fungi, as well as any of their cellular components or metabolic by-products. Where bioaerosol data specific to green-waste composting was not available, references to other feedstock types were used.

Both outdoor and indoor air in the natural environment contain all of the microorganisms, in variable amounts, that are associated with composting. A large variety of microorganisms can be present in the initial feedstock, depending on the specific materials used. Many of the organisms will be destroyed due to the heat of the composting process. However, the catalogue of organisms that can be present at any stage of a yard refuse composting process is quite long. Table 1 lists some of the most important agents that may be of health concern.

Common Types, Sources and Levels of Bioaerosol Exposure in Communities

This section presents information on the sources and range of concentrations for these agents in various environments. Determining background levels for airborne microorganisms is considerably more complex than for airborne chemical contaminants for several reasons. First, microbes are ubiquitous in the environment. Therefore, air or surface samples will almost always contain some bacteria or fungi. Many microbes grow and are released into the air at irregular intervals, or depend on some form of air turbulence or material disturbance to make them airborne. Because there is a large variation in size, shape and mass of microbial particles, some remain airborne for extended periods, while others fall back to the ground rapidly. In outdoor situations, temperature, humidity and wind speed are all critical factors in determining the airborne concentration of bacteria and fungi as well as their metabolic products. In addition to the variations in structure and biology of the organisms, the device used to measure them will also affect the result. Some samplers trap bacteria and fungi that must then be grown in a laboratory before they can be identified. This type of sampling device cannot identify dead or non-culturable bacteria, fungi or cell fragments. Therefore these organisms cannot be counted, even though they may still produce allergy or irritation. Because of these and other difficulties, it has not been possible to definitively establish “normal” or “expected” levels of bacteria or fungi in air.

Aspergillus fumigatus

Concerns about health effects from composting sites have tended to center around *Aspergillus fumigatus* for several reasons. First, this fungus is produced in abundance during the process of composting. Second, because of the fruiting structure (conidiophore) shape and the small size of its asexual spores (called conidia), the latter are easily dispersed into the air. Third, the conidia are small enough to reach the lung when inhaled. Fourth, *A. fumigatus* is one of the few fungi that can survive at human body temperature.

This fungus is found in soils worldwide and has been isolated from both temperate and tropical zones. It has been associated with both outdoor (grass, hay, bird’s nests and bird droppings, cattle and horse manure, forest litter, wood chips) (Domsch, et. al., 1980; Passman et. al., 1980) and indoor (refrigerator and bathroom walls, basements, bedding, house dust) (Wyngaarden and Smith, 1988; Slavin et. al., 1977) sources. Because it plays a prominent role in the natural decay process of leaves, wood and other organic matter, exposure to *A. fumigatus* and other bioaerosols occurs with common activities such as walking in the woods or park, mowing and raking lawns, gardening and potting house plants. Table 2 shows levels of *Aspergillus fumigatus* associated with various activities as measured in the Washington, D.C. area and provides a reference for background levels of this fungus. The conidia of this fungus are small (2 micrometers in diameter) and lightweight. These factors allow airborne *Aspergillus fumigatus* spores to be carried for some distance by light wind currents.

Numerous investigations have documented elevated levels of airborne *Aspergillus fumigatus* on site at composting facilities associated with compost turning or other processes involving material agititation (Millner, 1980; Kothary, 1984; Zwerling, 1991; E&A Env.Consulting, 1993). Only a few studies have measured concentrations of *Aspergillus fumigatus* upwind from their site (to estimate background level) as well as downwind at or beyond the facility boundary. Table 3 summarizes such data, demonstrating in each study the distance from composting operations to locations where *Aspergillus fumigatus* concentrations returned to background levels.

Bacterial Endotoxins

Bacterial endotoxins are the lipopolysaccharide portion of the outer layer of cell walls of Gram-negative bacteria. Endotoxins are very heat stable and are released into the environment during cell growth and after cells die (Bradley, 1979). Like *Aspergillus fumigatus*, Gram-negative bacteria are found everywhere in the natural environment. Because endotoxins are an integral part of the cell wall of every Gram-negative bacterium, the amount of endotoxins present in a specific environment is directly related to conditions that affect growth of these bacteria. Therefore, high levels of endotoxins are present in sewage water and leachate from compostable household waste, usually due to the growth of naturally occurring Gram-negative bacteria such as *Enterobacter* and *Klebsiella* species (Liesivuori et. al., 1994; Nielsen et. al., 1994). Storage of any organic matter, such as hay under wet conditions also favors the growth of these types of bacteria.

The level of endotoxins suspended in air depends on the degree of bacterial contamination of the affected material, handling or disturbance of the material and wind speed (outdoors) or ventilation rates (indoor air-handling system). Table 4 shows levels of endotoxins found in different environments.

Glucans

Cell walls of the fungi commonly found in green-waste composting contain β-(1→3)-D-glucan. This is another polysaccharide, but different from the Gram-negative bacterial cell wall. Measurement of glucan concentration has been proposed as a nonspecific indicator of fungal exposure. No references were found on airborne concentrations of glucans generated during composting operations.

Thermophilic Actinomycetes

Thermophilic actinomycetes are bacteria that thrive in environmental reservoirs with temperatures of 120-140° F. At these temperatures they produce significant amounts of enzymes which assist in the decay of organic matter. These bacteria can form spores and survive under adverse conditions such as temperatures of 50°C (122°F). They are found worldwide and have been isolated from soil, manure, grain, hay, compost and indoor humidification systems. Along with *Aspergillus fumigatus* these bacterial species participate in the decay of a wide variety of organic materials. Table 5 shows levels of thermophilic actinomycetes identified in the Washington, D.C. area. Air samples taken close to compost piles during turning operations found thermophilic actinomycetes at levels of $10^3 – 10^7$ cfu/m^3 (Lavoie, 1997; Lacy, 1997). No studies were found that measured these organisms within communities adjacent to composting facilities.

Mycotoxins

Mycotoxins are by-products of fungal metabolism. Not all fungi produce toxins and those that can, may generate different types and amounts of toxins depending on the strain of the fungus, the type of material (substrate) it is feeding on and the presence of other organisms. The most frequently studied mycotoxins are produced by species of *Aspergillus*, *Fusarium*, *Penicillium*, and *Stachybotrys*. The natural function of mycotoxins has not been clearly established, but they are considered to play a role in regulating competition with other microorganisms. Mycotoxins can accumulate on fungal spores, within the fungal body mass, or within the growth substrate. Spores are considered the most common vehicle for mycotoxin inhalation, as the toxins themselves are not volatile. Toxigenic fungi are found in all parts of the world and have been measured in stored grains, silage, hay and straw (Olenchock et. al., 1990; Morey et.al., 1989; Shen et. al., 1990).

Health Effects of Compost Bioaerosols

Aspergillus fumigatus

No significant new or insightful information concerning the relationship of *Aspergillus fumigatus* to health effects has been published since Technical Bulletin No.1, “Aspergillus, Aspergillosis, and Composting Operations in California”. Consult this document for a more complete description of health effects and the specific disease entities associated with *Aspergillus fumigatus*. A summary of known health effects associated with this fungus is presented below.

Infection (invasive growth of *Aspergillus fumigatus* into body tissues):

1. Healthy individuals are at minimal/negligible risk for infection from Aspergillus, regardless of the level of exposure (Millner et. al., 1994).
2. Healthy persons with lung damage in the form of pulmonary cavities, such as from tuberculosis or sarcoidosis, can develop aspergillus growth in these cavities. Overall health status and lung

function determine the prognosis for these patients (Glimp and Bayer, 1983). These persons would be susceptible to *Aspergillus* infection from any source, not specifically from composting.

3. Individuals with severely compromised immune systems (i.e., organ transplant patients, cancer therapy patients, those receiving long-term corticosteroid therapy, AIDS patients, persons with congenital defects and children with cystic fibrosis) may be at greater risk of infection. Persons with these conditions are now more frequently living in the community rather than in hospitals. However, these individuals are also at risk of infection from *Aspergillus fumigatus* and other microbes in the general environment, which contains natural sources of these organisms (Pope et. al., 1993; Millner et. al., 1994).

<u>Allergy</u> (immunologically based reaction to a small amount of material in the environment after a period of exposure that sensitizes specialized cell systems):

1. Persons at risk are those with a genetic predisposition to react to allergens in the environment. It has been estimated that 40% of the U.S. population possesses this genetic trait, 20% will develop clinical symptoms of allergy (e.g., ‘hay fever’, sinusitis, asthma or allergic skin disease) at some time in their lives, 10% will have asthma symptoms requiring treatment with 5% having potentially life-threatening asthma (Pope, 1993).
2. No data are available regarding threshold concentrations of *Aspergillus fumigatus* that evoke allergic symptoms. However, threshold concentrations for two other common outdoor airborne molds are estimated to be 100 *Alternaria* spores/m^3 and 3000 *Cladosporium* spores/m^3 (Gravesen, 1979).
3. Currently available epidemiological studies indicate no association between occurrence of allergic, asthmatic, or either acute or chronic respiratory diseases in the general public at or around the several open-air facilities and one enclosed composting site that have been evaluated (Millner et. al., 1994).
4. A small percentage (6%) of asthmatics who are sensitive to *Aspergillus* can develop allergic bronchopulmonary aspergillosis, a condition in which *Aspergillus* grows in the mucus that normally lines the walls of larger airways (Greenberger et. al., 1988). This growth may become extensive enough to block the involved airway. Despite this proliferation in the airways the fungus does not invade through the airway wall into the lung. It does, however, induce inflammatory and allergic changes in the adjacent lung that can lead to fibrosis and severe loss of lung function. The factors that lead to the development of allergic bronchopulmonary aspergillosis in some asthmatics and not others are not well understood.

<u>Bacterial Endotoxins</u>

When Gram-negative bacterial cells (either living or dead) are inhaled, they are engulfed by macrophages, cells that line the respiratory and react to the presence of foreign substances. Macrophages process the bacterial cells and release endotoxins. The toxins then lead to lung inflammation that can produce rapidly developing symptoms of fever, malaise, cough, diffuse aches, nausea and shortness of breath. Endotoxins can also cause constriction of the airways in asthmatics leading to asthma attacks (Michel, 1989, 1992; Rylander, 1989). Because these substances are toxins they are capable of stimulating inflammation in the airways of healthy people (Michel, 1997). It is not necessary to be sensitized or predisposed to experience this effect. Acute health effects have been demonstrated in experimental exposure studies with human volunteers and in epidemiological studies of occupationally exposed workers (Castellan, 1987; Rylander, 1985;). There are no data indicating carcinogenic, mutagenic or reproductive effects from exposure to endotoxins.

In contrast to their adverse effects on lung function, endotoxins are known to stimulate the immune system by causing macrophages to produce tumor necrosis factor alpha and interferons. Several studies have shown that populations exposed to high levels of airborne endotoxins have low rates of lung cancer (Hodgeson, 1990; Rylander, 1990).

Adverse health effects due to inhalation of endotoxins have been documented at exposures as low as 8-10 nanograms/m^3 (ng/ m^3). In recent studies, airborne endotoxin concentrations measured on site at a Norwegian outdoor composting facility ranged from 0.0-7.3 ng/m^3 (Heldal et.al., 1997), and averaged 0.8 ng/m^3 at a Danish plant (Sigsgaard et.al., 1994). There have been few studies that have measured endotoxin levels in communities adjacent to composting facilities. In one such study of a German plant with outdoor windrow curing, sieving and bulk storage from biowaste compost, airborne endotoxin was found at 20 ng/m^3 near the sieving operation, while levels dropped to 0.24 ng/m^3 at a distance of 500 feet downwind in an adjoining community (Danneberg et.al., 1997). These studies support the theory that levels of endotoxins in air may approach significance on site, but decrease rapidly with increasing distance from the source. However, additional studies need to be done to more thoroughly characterize the distribution of endotoxins in different types of composting operations.

No United States government agency has set exposure limits for airborne endotoxins. However, the International Commission on Occupational Health published permissible endotoxin concentrations for two agricultural industries based on avoidance of acute health effects (Rylander, 1989). These guidelines recommended air concentrations of less than 20 ng/m^3 for workers in cotton mills and less than 470 ng/m^3 in the animal feed industry. The Dutch Expert Committee on Occupational Standards has proposed an occupational exposure limit of 4.5 ng/m^3 of airborne endotoxin based on personal inhalable dust exposure measured as an eight hour time weighted average (Heederik et.al., 1997).

Glucans

When inhaled, glucans depress the normal functioning of macrophages, similar to the effects described above for endotoxins. Thus, glucans can also compromise the macrophage's ability to react to other foreign substances in the respiratory system. Recent laboratory experiments using guinea pigs have suggested that the combined presence of glucans and bacterial endotoxin leads to more severe airway inflammation than either alone, and that this combination of chemicals of bacterial and fungal origin may produce long-term changes in the lung (Fogelmark, et. al., 1994). There are currently few studies involving human subjects exposed to glucans. At present there are no data correlating the presence of airborne glucans in organic dust and human heath effects occurring after dust inhalation (Williams, 1994).

Thermophilic Actinomycetes

Long term inhalation of large numbers of thermophilic actinomycetes can produce hypersensitivity pneumonitis (HP), a lung disease characterized by inflammatory cell accumulations (granulomas) within the lung tissue. Exposure to high levels of many types of fungus-contaminated organic dusts, such as from sugarcane, hay, mushroom compost, wood dust, wood chips and leaves can produce HP. It is not clear whether this disease is due to toxic or allergic effects of these agents.

Two forms of this disease have been described: acute and chronic. The acute form is associated with exposure to massive amounts of bacteria or fungi (billions of organisms/m^3) which produce symptoms of fever, chills, muscle aches, cough and difficulty breathing within 8-12 hours of exposure. Since these symptoms resolve within 24-48 hours and are non-specific the acute form of hypersensitivity pneumonitis can be confused with other conditions such as influenza, asthma and viral pneumonia. Repeated acute episodes are thought to predispose to the second or chronic form of HP which can include irreversible lung damage (Weber, 1993). The incidence of HP in chronically exposed persons such as hay or grain farmers is generally low, about 0.03 percent in Swedish farmers (Malmberg et. al., 1988) and 0.42 percent in a group of Wisconsin farmers (Gruchow et. al., 1981).

Occupational exposure to compost in mushroom-growing operations is a well-known cause of hypersensitivity pneumonitis (Fink, 1993; Sanderson, 1992). While there are no reports of HP in workers at U.S. commercial composting facilities, cases has been reported involving one Belgian worker (Vincken & Roels, 1984), one worker at an improperly ventilated Japanese greenhouse (Yoshida et. al., 1993), and one residential composter who had shoveled wood chips and leaves (Weber, et. al., 1993). No long-term studies of yard-waste compost workers are available for review at this time.

Mycotoxins

Most of the information available on health effects due to mycotoxin exposure is derived from studying animals that have eaten mycotoxin-contaminated grains. It is only in the last decade that concern about exposure to airborne mycotoxin has arisen. Therefore most of our knowledge about effects of inhalation of these toxins is still based on limited experimental data and a few reports from field investigations (Croft, et.al., 1986**;** Johanning et. al., 1996). Under laboratory conditions using high doses, mycotoxins have caused damage to the immune system, tremors or other nervous system effects and cancer in experimental animals (Ciegler et. al., 1981; Sorenson et. al., 1986). The dose sufficient to cause such changes varies with the toxin, the experimental animal species, and the route of administration (i.e., given by mouth, injected under the skin, etc.). Currently, evidence relating human disease to mycotoxin inhalation is limited. However, in a recent investigation in Cleveland, the Centers for Disease Control and Prevention found an association between the presence indoors of several toxigenic molds and an increased risk of massive, acute pulmonary hemorrhage in infants (Montaña et. al., 1997). There is insufficient information in this or other studies to determine if exposure to these toxigenic molds alone is sufficient to cause lung hemorrhage in infants or if other conditions are also required. The dose of mycotoxin necessary to cause such damage in human infants is not known.

Factors Affecting Bioaerosol Exposure Levels from Green-Waste Composting Facilities

The primary exposure of potential concern is inhalation of organic dusts containing bioaerosols and their metabolic products generated from compost sites. Due to the possibility of health effects from several different types of bioaerosols, including but not limited to *Aspergillus fumigatus*, compost facility operators should use methods to keep dust generated by the composting process at levels as low as reasonably achievable. Such dust control benefits and protects both employees working at the site and any nearby community members. Minimizing airborne dust can be accomplished through a combination of design, siting, maintenance and operational decisions. In addition to this report, the California Integrated Waste Management Board, with the assistance of DHS, will be providing guidance documents and training workshops that will focus specifically on these factors.

Design

Physical characteristics at a proposed composting site, such as shape of the terrain and weather conditions, may require consideration of different methods of aerosol control. Proximity of sensitive subpopulations such as patients in a hospital, a nursing home or other care facility for immune-compromised persons should also be taken into account. Conditions such as these will need to be factored into the decision-making process when evaluating proposed new facilities.

Complete enclosure can significantly decrease bioaerosol distribution offsite from the composting facility. However, careful attention must be paid to worker exposures and personal protective equipment use in those circumstances. Information from the WSSC Site II studies (Lees et. al**.**, 1987; General Physics Corp., 1991) indicates that on-site *Aspergillus fumigatus* levels increased 11-fold when the facility was enclosed. Biofilters or chemical scrubbers have been evaluated primarily for their ability to control odors. These devices have not been specifically examined for their capacity to remove and retain bioaerosols.

Siting

Many factors are considered when deciding on a location for a large composting facility. One such issue is whether a minimum distance (buffer zone) should be established between the composting operation and the nearest offsite building or public use area. There is no recommended minimum buffer zone width in the current Integrated Waste Management Board's regulatory requirements (California Code of Regulations, 1997). This is a change from previous regulations, which required a minimum 300-foot buffer zone (for green- waste composting facilities only) from active compost materials to any residence, school or hospital. This buffer zone width was established to address nuisance odor and aesthetic issues, rather than bioaerosol health effects. Currently, LEA's rely upon local zoning and building codes in determining the need for and size of buffer zones on a site-specific basis. In making siting decisions, considerations should include facility size, design, operational factors such as dust control measures, site topography, local meteorological conditions (windrose data) and adjacent land use (Millner et. al., 1994). In particular, types of adjacent occupied buildings and health status of occupants (hospitals, long-term care facilities, schools, etc.), as well as their distance from the facility should be taken into account.

Concentrations of Aspergillus fumigatus spores at various distances from several composting facilities are listed in Table 3. While some studies of composting operations have recommended buffer zones between facilities and residential areas, specific widths of such zones have not been identified. One report recommended a 2-mile buffer zone, but did not supply supporting data for this recommendation (Kramer et. al., 1989). There is insufficient information in the current literature, including a lack of health risk data and regulatory standards, with which to define a science-based minimum buffer zone width.

Regulations for siting of compost facilities vary from state to state; some require buffer zones, while others do not. Table 6 describes buffer zone requirements in some selected U.S. states and Canadian provinces. It should be noted that the majority of these buffer zones are not based on public health threat from bioaerosol exposure but rather address aesthetic or nuisance issues.

Maintenance and Operations

The California Integrated Waste Management Board's Technical Bulletin No.1, "Aspergillus, Aspergillosis, and Composting Operations in California" contains many useful suggestions for minimizing dust production at composting sites. Each facility should critically evaluate its dust control measures to minimize bioaerosol releases. In Millner et. al. (1980), mechanical agitation of compost materials and feedstock was the major source of airborne dust. Measurements conducted during mechanical agitation of compost with a front-end loader found downwind concentrations of thermophilic actinomycetes and fungi 150-200 times higher than in the immediately adjacent area (Millner et. al., 1994).

Employee Protection

In addition to design, siting and maintenance factors, some additional precautions are suggested for compost facility workers. All applicants for positions at a compost site should be trained and educated on hazards associated with the job. Training should include information on the nature of the organic decay process and the potential for greater exposure to bioaerosols in some job categories.

All personnel working with compost should be trained in proper use of equipment, specific methods utilized at that site to minimize dust and bioaerosol production, and in compost-related health issues. California Occupational Safety and Health Administration provides consultation services to assist facility managers in determining appropriate personal protective equipment needs. Proper training in the use and fitting of all personal protective equipment, especially respirators if required, must be part of on-going occupational education programs at each facility.

What about air monitoring?

This section is a brief introduction to the very complex field of bioaerosol monitoring. This information is not presented as a recommendation for or against air monitoring, but to provide interested parties with some information about these procedures. Due to differences in design and operation of green-waste compost facilities, varied geography and differing weather conditions throughout California, it is not possible to recommend a single specific strategy for bioaerosol monitoring that would work for all sites. There is no cookbook approach for bioaerosol sampling.

There are several issues that should be understood before considering an air-monitoring plan. First, natural decay processes in the surrounding areas produce the same bioaerosols that are generated by composting facilities. Thus measurement of background levels is an important consideration. Second, concentrations of natural decay bioaerosols vary extensively hour to hour as well as by season and other factors. Therefore many measurements are needed to establish the range of background bioaerosol levels. Third, there are no regulatory standards that define allowable limits for airborne microorganisms or their metabolites. Consequently there is no government agency-defined maximum permissible level that can be used for comparison with results from a monitoring program. Fourth, there is no single sampling device that is appropriate for acquiring all the major bioaerosols and their metabolites. Use of multiple samplers and acquisition of many samples make these studies very labor intensive and costly. Fifth, there are no data available that identify the lowest exposure level at which health effects might occur from a complex mixture such as compost bioaerosols.

If air sampling is being considered it is prudent to seek assistance from environmental consultants with experience in designing sampling plans for fungal bioaerosols. Appendix A provides a brief overview of some factors to consider in designing a compost bioaerosol sampling protocol.

Summary and Areas that Need Further Investigation

Studies to date that have evaluated the relationship between compost bioaerosol release, levels of bioaerosols off-site and health effects in adjacent communities indicate:

- no increased risk for infection from exposure to *Aspergillus fumigatus* among healthy persons in the general population or the composting work force;

- sensitive subpopulations including persons with compromised or suppressed immune systems may be at increased risk of infection by *Aspergillus fumigatus*, from any source, not just composting;

- asthmatics and those with allergic predisposition may be at increased risk for developing allergic reactions to one or several compost bioaerosols, as well as a variety of common ambient air components such as pollen and house dust; and

- compost worker exposure to bioaerosols may be high enough in some facilities to increase risk of some types of health problems. Previous studies of U.S. compost workers have not documented an increase in risk with occupational exposure, but limitations in the number and design of the studies make drawing firm conclusions difficult. Several studies from European countries have demonstrated elevated bioaerosol exposure to compost workers and have found associations between these high levels and worker health problems (Sigsgaard, 1994, 1997, Poulsen, 1995, Ivens 1997).

Bioaerosol concentrations in communities downwind from composting sites have been difficult to evaluate due to limitations in the available microbial sampling techniques. Thus, measurements have been intermittent and do not provide an accurate view of the variations due to season, time of day, temperature, wind speed and direction, humidity, compost operational factors, and other components. Studies that monitor objective health indicators and nuisance parameters in larger numbers of persons in adjacent communities are needed.

The effectiveness of operational practices such as adding water to composting material and other dust-control strategies in controlling bioaerosol as well as particulate emissions in green-waste facilities has not been completely explored, especially taking into consideration the different practices necessitated by design and feedstock variations. Additional work is also needed to determine whether biofilters or chemical scrubbers used in enclosed facilities can remove bioaerosols, in addition to odors.

REFERENCES

Bradley SG. Cellular and molecular mechanisms of action of bacterial endotoxins. Ann Rev Microbiol 33:67-94. 1979.

California Code of Regulations (1997). Title 14: Natural Resources. Division 7: California Integrated Waste Management Board. Chapter 3.1: Composting Operations Regulatory Requirements.

CIWMB (California Integrated Waste Management Board). Personal communication, 1997.

California Integrated Waste Management Board. LEA Advisory No. 6, December 16, 1993 Technical Bulletin No.1, Aspergillus, Aspergillosis, and Composting Operations in California. Sacramento, California.

Ciegler A, Burmeister HR, Wesonder RF and Hesseltine CW. Mycotoxins: Occurrence in the environment. in: Mycotoxins and N-nitroso Compounds: Environmental Risks. Vol. 1, CRC Press, Inc., Boca Raton, Florida. 1981.

Croft WA, Jarvis BB, Yatawara CS. Airborne outbreak of trichothecene toxicosis. Atmospheric Environment. 20(3):549-552. 1986.

Danneberg G, Grüneklee E, Seitz M, Hartung J, Driesel A. Microbial and endotoxin immissions in the neighborhood of a composting plant. Ann Agric Environ Med. 4:169-173. 1997.

Domsch KW, Gams W, Anderson T-H. Compendium of Soil Fungi. Academic Press, London, 2 vols. 1980

E & A Environmental Consultants, Inc. Report to Earthgro. Lebanon, Connecticut. 1993.

Epstein E. Protecting workers at composting facilities. Biocycle. 39(9):69-77. 1996

Fink JN. Hypersensitivity Pneumonitis. in: Middleton E, Reed CE, Ellis EF, et al (editors). Allergy Principles and Practice. Chapter 54. pp 1415-1431. 1993.

Fogelmark B, Sjostran M, Rylander R. Pulmonary inflammation induced by repeated inhalations of β(1-3)-D-glucan and endotoxin. Int J Exp Path. 75:85-90. 1994

General Physics Corp. Environmental Services Division. Data results: Revised bioaerosol monitoring program for the Washington Suburban Sanitary Commission. Montgomery County Regional Composting Facility. General Physics Corporation, Silver Springs, Maryland. 1991.

Glimp RA and Bayer AS. Pulmonary aspergilloma: Diagnostic and therapeutic considerations. Arch Int Med 143:303-308. 1983.

Gravesen S. Fungi as a cause of allergic disease. Allergy 34:135-154. 1979.

Great Lakes Center for Occupational & Environmental Safety & Health. Environmental Characterization of Bio-Aerosol Emissions from the DK Recycling Systems, Inc. Composting Facility in Lake Forest, Illinois. HHE Report 96-001. Univ. of Illinois at Chicago. 1996.

Greenberger PA, Patterson R. Allergic bronchopulmonary aspergillosis and the evaluation of the patient with asthma. J Allergy Clin Immunol 81:646, 1988.

Gruchow HW, Hoffman GR, Marx JJ, Emanuel DA, Rimm AA. Precipitating antibodies to farmer's lung antigens in a Wisconsin farming population. Am Rev Resp Dis. 124:411-415. 1981.

Heederik D and Douwes J. Towards an occupational exposure limit for endotoxins? Ann Agric Environ Med. 4:17-19. 1997.

Heida H, Bartman F, von der Zee SC. Occupational exposure and indoor air quality monitoring in a composting facility. Amer Ind Hyg Assoc J. 56(1):39-43. 1995.

Heldal K, Wijnand E, Bergum M. Bioaerosol exposure during handling of source separated household waste. Ann Agic Environ Med. 4:45-51. 1997.

Ivens UI, Ebbehøf N, Poulsen OM, Skov T. Gastrointestinal symptoms among waste recycling workers. Ann Agric Environ Med. 4:153-157. 1997

Johanning E, Biagini R, Hull D, Morey P, Jarvis B, Landsbergis P. Health and immunology study following exposure to toxigenic fungi (*Stachybotrys chartarum*) in a water-damaged office environment. Int Arch Occup Environ Health. 68:207-218. 1996.

Kramer MN, Kurup VP, Fink JN. Allergic bronchopulmonary aspergillosis from a contaminated dump site. Amer Rev Respir Dis. 140:1086-1088. 1989.

Lacey J. Actinomycetes in composts. Ann Agic Environ Med. 4:113-121. 1997.

Lavoie J, Alie R. Determining the characteristics to be considered from a worker health and safety standpoint in household waste sorting and composting plants. Ann Agic Environ Med. 4:123-128. 1997.

Lees PSJ, Tockman MS. Evaluation of possible public health impact of WSSC Site II sewage sludge composting operations. Johns Hopkins University, School of Hygiene and Public Health. Report prepared for Maryland Department of Health and Mental Hygiene. Baltimore, Maryland. 1987.

Liesivuori J, Kotimaa M, Laitinen S, Louhelainen K, Ponni J, Sarantila R, Husman K. Airborne endotoxin concentrations in difference work conditions. Am J Ind Med 25:123-124. 1994

Malmberg P, Rask-Andersen A, Hoglund S, Kolmodin-Hedman B, Gurnsey Jr. Incidence of organic toxic dust syndrome and allergic alveolitis in Swedish farmers. Int Arch Allergy Appl Immunol 87:47-54. 1988.

Michel O, Duchateau J, Sergysels R. Effect of inhaled endotoxin on bronchial reactivity in asthmatic and normal subjects. J. Applied Physiol 66:1059-64. 1989.

Michel O, Ginanni R, Le Bon B, Content J, Duchateau J, Sergysels R. Inflammatory response to acute inhalation of endotoxin in asthmatic patients. Am Rev Respir Dis. 146:352-357 .1992.

Millner PD, Bassett D, Marsh PB. Dispersal of *Aspergillus fumigatus* from sewage sludge compost piles subjected to mechanical agitation in open air. Appl Environ Microbiol 39:1000-1009. 1980.

Millner PD, Olenchock SA, Epstein e, Rylander R, Haines J, Walker J, Ooi BL, Horne E, Maritato M. Bioaerosols associated with composting facilities. Compost Sci & Util 2(4):6-57. 1994.

Montaña E, Etzel RA, Allan T, Horgan TE, Dearborn DG. Environmental risk factors associated with pediatric idiopathic pulmonary hemorrhage and hemosiderosis in a Cleveland community. Pediatrics 99(1). 1997.

Morey PR, May JJ, Pratt DS, Stallones L, Olenchock SA, Sorenson WG. Dust and microbial exposures during silo unloading. in J.A. Doeman and D.W. Cockcroft (editors), Principles of Health and Safety in Agriculture. CRC Press, Inc., Boca Raton, Florida, pp. 182-184. 1989.

Neilsen BH, Würtz H, Hoist E. Endotoxin and microorganisms in percolate derived from compostable household waste. Amer J Ind Med 25:121-122. 1994.

New York Department of Health. A prospective study of health symptoms and bioaerosol levels near a yard waste composting facility - Islip Composting Facility. Center for Environmental Health. Albany, New York. 1994.

Olenchock SA, Christiani DC, Mull JC, Shen Y-e, Lu P-l. Airborne endotoxin in a rice production commune in The People's Republic of China. J Toxicol Envir Health 13:545-551. 1984.

Olenchock SA, Sorenson WG, Marx JJ, Parker JE. Microbial contamination and immunologic reactivity of stored oats. Biodeterioration Res. 3:479-488. 1990.

Passman FJ. Monitoring of *Aspergillus fumigatus* associated with municipal sewage sludge composting operations in the State of Maine. Portland Water District, Portland, Maine. 1980.

Pope AM, Patterson R, Burge H (editors). Indoor Allergens. Institute of Medicine. National Academy Press. Washington, D.C. 1993.

Poulsen OM, Breum NO, et. al. Sorting and recycling of domestic waste. Review of occupational health problems and their possible causes. Sci Tot Envir. 168:33-56, 1995.

Rippon JW. Medical Mycology. The Pathogenic Fungi and The Pathogenic Actinomycetes. W.B. Sauders, Co. Philadelphia, Pennsylvania. 1974.

Rylander R, Haglind P. Exposure of cotton workers in an experimental cardroom with reference to airborne endotoxins. Environ Hlth Perspect 66:83-86, 1986.

Rylander R, Bake B, Fischer JJ, Helander IM. Pulmonary function and symptoms after inhalation of endotoxin. Am Rev Resp Dis. 140:981-86,1989.

Sanderson W, Kullman G. Outbreak of hypersensitivity pneumonitis among mushroom farm workers. American Journal of Industrial Medicine 22:859-872, 1992.

Shen Y-e, Sorenson WG, Lewis DM. Olenchock SA. Microbiological analyses and inflammatory effects of settled dusts from rice and hay. Biomed Environ Sci 3:353-363. 1990.

Sigsgaard T, Malmros P, Nersting L, Petersen C. Respiratory disorders and atopy in Danish refuse workers. Am J Resp Crit Care Med 149:1407-1412. 1994.

Sigsgaard T, Hansen JC, Malmros P. Biomonitoring and work related symptoms among garbage handling workers. Ann Agric Environ Med 4:107-112. 1997.

Slavin RG, Winzenburger. Epidemiologic aspects of allergic aspergillosis. Annals Allergy 38:215-218, 1977.

Sorenson WG, Gerbarick GF, Lewis DM, Castranova V. Toxicity of mycotoxins in the rat alveolar macrophage *in vitro*. Proc New Orleans Conference on Agricultural Dusts. Environ Health Perspect 66:45-53. 1986.

Smid,T, Heederik D, Mensink G, Houba R, Boleij JSM. Exposure to dust, endotoxin, and fungi in the animal feed industry. Am Ind Hyg Assoc J 53:362-368. 1992.

Vincken W, Roels P. Hypersensitivity pneumonitis due to *Aspergillus fumigatus* in compost. Thorax 39:74-75. 1984.

Weber S, Kullman G, Petsonk E, Jones WG, Olenchock S, Sorenson W, Parker J, et. al. Organic dust exposures from compost handling: case presentation and respiratory exposure assessment. American Journal of Industrial Medicine 24:365-374. 1993.

Williams DL. (1∏3)-ß-**D**-Glucans. in Organic Dusts: Exposure, Effects and Prevention. Rylander R and Jacobs R (ed). Lewis Publishers/CRC Press, Inc., Boca Raton, Florida. 1994.

Wyngaarden JB, and Smith LH(ed.). Cecil Textbook of Medicine. 18th Edition, Chapter XVIII, Infectious Diseases:Section 376, Aspergillosis. W. B. Saunders, Co. Philadelphia, Pennsylvania. 1988.

Yoshida K, Ueda A, Yamasaki H, Sato K, Uchida K, Ando M. Hypersensitivity pneumonitis resulting from *Aspergillus fumigatus* in a greenhouse. Archives of Environmental Health 48(4):260-262. 1993.

Zwerling EM, Strom PF. Levels of *Aspergillus fumigatus* at yard waste composting facilities in New Jersey. Theobald Smith Soc. (Abstr.) Annual Meeting.

TABLE 1

Bioaerosols of concern in yard-waste composting

Category	Type of Organism	Specific Genera	Pathogenic Mechanisms
Microorganisms	thermophilic actinomycetes	*Streptomyces*	allergens
	Gram-negative bacteria	*Pseudomonas, Shigella, Yersinia, Actinobacter*	infectious agents, endotoxins
	fungi	*Aspergillus, Penicillium Mucor, Rhizopus*	infectious agents, allergens, mycotoxins, glucans
Arthropods	mites		allergens
Organic or wood dust			irritants, allergens, endotoxins

(source: from Epstein, 1996; Heida et al., 1995, Millner et al., 1994)

TABLE 2

Seasonal counts of viable A*spergillus fumigatus* particles in air in the Washington, D.C. Metropolitan Area during 1979-1980.

	Seasonal Counts (CFU / m3)			
Site	Fall	Winter	Spring	Summer
Lawn				
during mowing	1	5	2	0
with mulch	75	2	6	686
under trees	3	0	5	4
of hospital	2	0	0	0
of park	8	4	24	2
Wooded Area				
arboretum	4	1	6	136
nature trail	56	0	10	8
road side	1	5	2	3
Agricultural				
corn field	1	0	0	4
barn	2,070	105	352	5,550
barnyard	44	0	35	4
poultry coop	21	93	2,060	6
mushroom house	88,700	740,000	580,000	67,100
brush pile	1	1	25	5
Refuse				
municipal dump	6	2	0	5
supermarket dumpster	2	0	0	12
Greenhouse				
potting room	868	1,350	1,070	9,810
low humidity	NS	11	312	1
high humidity	NS	0	152	2
Pool - indoor				
Library-stacks	171	0	0	0
Attic	NS	1	1,160	125
Zoo-birdhouse	5	0	42	2
Boiler room	30	38	1	1
Reference Sites				
School playground	6	1	12	9
University parking lot	7	1	2	4
Shopping center	11	1	7	3

* during disturbance of material (source -Millner et al., 1994 used with permission)

TABLE 3

Distance from Compost Facilities to Site where Bioaerosol Concentration equals Background Level

Facility Source - Type	Bioaerosol Sampled	Sampling Device	Distance Measured From	Distance (in feet) to Background Bioaerosol Measurement	Study Date	Reference	Comments
Green-waste	Aspergillus fumigatus	NA*	NA	1500	1991	Zwerling, Strom	
Green-waste	Aspergillus fumigatus	NA	Facility	500	1993	E&A Env. in Epstein, 1997	
Green-waste	Aspergillus fumigatus	Burkard spore trap + RCS**	Facility	1775	1994	New York Hlth Dept	When downwind - A.f. at 1775 ft was up to 4 times higher than reference (p<0.05)
Green-waste #	Total culturable fungi	Andersen Kramer-Collins spore trap	Facility	950	1996	Great Lakes Center for Occ & Env Safety and Health, UIC	
Green-waste	Aspergillus fumigatus	Sartorius MD 8	Compost	1650	1997	Danneberg, et al.	modeled at 500 m (1650 ft), measured at 150 m
Household	Aspergillus fumigatus	Andersen	Compost	330	1997	Lavoie, Alie	
Biosolids	Aspergillus fumigatus	NA	Facility	1300	1983	Hampton Roads, in Epstein, 1997	
Biosolids	Aspergillus fumigatus	Andersen	Compost	575	1983	Clayton Environ.	575 ft = site boundary
Biosolids	Aspergillus fumigatus	Andersen	Site center	492	1983	Passman	
Biosolids	Aspergillus fumigatus	slit air sampler	Compost	>820	1984	Kothary, Chase	
Biosolids	Aspergillus fumigatus	Andersen	Compost	1640	1980	Millner, et al.	from air dispersion model
Biosolids	Aspergillus fumigatus	Andersen	Compost	2640	1983	Cookson, et al.	

* NA = not available
** RCS = Reuter Centrifugal Sampler
\# counted total fungal colonies, did not identify to genus or species level

TABLE 4

Examples of Levels of Airborne Endotoxin in Different Environments

Location	**Levels (nanograms/m^3)**	**Statistic**	**Reference**
Humidifiers	400	maximum	Rylander & Haglind, 1984
Animal feed production	1,900	maximum	Smid et al., 1992
Grain farms, grain dryer emptying	16,100	mean	Liesivuori et al., 1994
Cotton mill	6-779	range	Castellan et al., 1987
Household waste composting plant	20.7	single sample	Danneberg et al., 1997
Garden waste composting plant	0.8	mean	Sigsgaard et al., 1994
Fur animal farming, bedding material	62-1,950	range	Liesivuori et al., 1994
Rice production	1.3		Olenchock et al., 1984
Waste water treatment plant	55	mean	Liesivuori et al., 1994
Household waste processing	2.5	mean	Sigsgaard et al., 1994

TABLE 5
Seasonal Counts of Viable Thermophilic Actinomycetes in Air in the Washington, D.C-Metropolitan Area During 1979 - 1980

	Seasonal counts (CFU / m^3)			
Site	Fall	Winter	Spring	Summer
Lawn				
during mowing	2	2	7	0
with mulch	0	0	0	1
under trees	0	0	5	2
of hospital	0	5	0	1
of park	0	8	2	12
Wooded Area				
arboretum	5	0	5	5
nature trail	0	2	4	5
road side	0	1	4	0
Agricultural				
corn field	2	2	1	5
barn	NS	118	0	5
barnyard	NS	132	1	51
poultry coop	0	29	43	1
mushroom house	204	24,600	35,800	3,470
brush pile	1	4	10	5
Refuse				
municipal dump	1	4	2	6
supermarket dumpster	1	1	0	I
Greenhouse				
potting room	13	0	1	0
low humidity	NS	2	12	2
high humidity	NS	0	4	0
Pool- indoor	11	10	3	1
Library-stacks	0	2	4	7
Attic	NS	0	2	4
Zoo-birdhouse	5	1	4	8
Boiler room	4	0	0	1
Reference Sites				
School playground	3	3	3	3
University parking lot	2	1	2	2
Shopping center	2	2	3	3

(source -Millner et al., 1994 used with permission)

TABLE 6

Buffer Distance Requirements for Composting Facilities in Some States and Canadian Provinces*

Illinois	In 1991 Illinois passed regulations that existing compost facilities must be located at least 200 feet from any residence while any facility developed or expanded after 1991 must have at least 1/8 mile (660 feet) between the facility property line and the nearest residence. Illinois E.P.A. staff indicated these distances were selected to address odor problems not bioaerosols.
Tennessee	In 1995, Chapter 1200-1-7, Solid Waste Processing and Disposal was amended to include a new rule, 1200-1-7.11. Composting, that covers both specifications for facilities and sale of compost within Tennessee. Among the facility general prerequisites are the following buffer zone requirements: minimum 100 feet from compost to facility property lines, minimum 500 feet from compost to any residence unless the owners agree in writing to a shorter distance, and minimum 200 feet from compost to water courses. These distances are the same as those required for landfills in Tennessee.
Texas	If total volume of materials to be processed is >2,000 cubic yards and if grinding occurs on site, "setback distance from all property boundaries to the edge of the area receiving, processing or storing feedstock or finished product shall be at least 50 feet". If no grinding occurs onsite, there is no setback required. There are no guidelines or regulations requiring buffer distance between facility boundary and adjacent occupied spaces.
Saskatchewan	No rules on size of buffer zone are incorporated into provincial law. However, according to Saskatchewan Environment and Resource Management, a minimum of 500 meters (1640 feet) must be allowed between the compost site and any sensitive neighboring land uses, such as residences, restaurants, hotels/motels, schools, churches or public buildings. They also suggest that it is prudent to provide at least 50 meters (164 feet) between the composting operation and the property line. The 500 meter buffer distance was apparently taken from the provincial regulations regarding siting of landfills.
British Columbia	Distance between composting operation and property boundary must be not less than 50 m (164 feet) of which the 15 m (50 feet) closest to the property boundary must be reserved for natural or landscaped screening (berms or vegetative screens).

*** This is not a complete list of all states and Canadian provinces with buffer distances, but a convenience sample. Most of these buffer distances were defined to address nuisance odors and aesthetics.**
(source – modified from Epstein, 1997 and personal communications, 1998)

APPENDICES

Appendix A

BIOAEROSOL MONITORING

There are many factors to think about if bioaerosol sampling is being considered.

- **Multiple sampling devices may be necessary**
  - Bioaerosols occur in particle sizes ranging from less than 1 micrometer to more than 100 micrometers. It is not currently possible to accurately measure aerosols over this entire range with a single sampling device.
  - Some devices trap spores which must later be grown in a laboratory before they can be identified and counted. However spores or fungal fragments that do not grow in the laboratory may still cause health effects, so it may be appropriate to use samplers which also collect "non-viable" or "non-culturable" particles.
  - Samplers that pump a known volume of air into contact with the growth medium or contact surface give the most accurate representation of bioaerosol components.

- **Many air samples may need to be collected.**
  - Air samples should be representative of the aerosol over space and time. The ideal sampling plan would include continuous sample collection over the entire exposure period of interest. This would allow the full range of exposure to be determined. Optimally, such samples would be collected for twelve months, to document the full effect of all seasons and various weather conditions on bioaerosol levels. However, shorter sampling timeframes can also provide useful information, particularly if measurements are made during the months when composting activities are most frequent.
  - A sufficient number of samples must be taken to allow analysis of the data and determination of any statistically significant differences. A biostatistician can provide useful assistance in this area.
  - Selection of monitoring sites to determine the effect of composting facilities on bioaerosols should take into consideration where neighboring populations, especially potentially sensitive subpopulations, are located. If there are schools, playgrounds, hospitals or convalescent homes on property adjacent to a compost facility, researchers may wish to concentrate resources in these areas.

- **Background samples should be collected simultaneously whenever target area sampling is performed.**
  - Due to the extreme variation in microbial concentrations over short periods of time, it is very important that background samples always be collected for comparison with target area samples. Useful background samples can be collected in one or more locations upwind from the facility.

- **Bioaerosol sampling, analysis and interpretation of results involves many highly trained individuals.**
  - Many sampling devices require a high input of human attention in collection, preparation and reading of the samples. Individuals with expertise in environmental microbiology should be consulted during the planning process of any bioaerosol monitoring plan. Appendix B lists laboratories with experience in identification and culture methods for environmental bacteria and fungi.
  - Monitoring protocols can become expensive due to the large number of samples and human expertise required.
  - Limited numbers of individuals experienced in environmental microbiology make it difficult to plan large scale monitoring protocols.

Each of these factors is a site-specific issue and must be addressed on an individual project basis. **<u>The most important first step in developing a bioaersol monitoring program is to define your research question.</u>** The following outline is provided to illustrate some of the concepts that should be included when formulating such a program.

CONSIDERATIONS IN PLANNING A STUDY FOR A NON-ENCLOSED GREEN-WASTE COMPOSTING FACILITY

Outline

I. What is your research question? Determine as specifically as possible the question that you want to address with an air-monitoring program.

A. Example 1 - Research question - Are median levels of airborne *Aspergillus fumigatus* statistically significantly higher in a community adjacent to the composting facility during compost operations than when composting is not occurring?

B. Example 2 - Research question - Are median levels of airborne *Aspergillus fumigatus* and endotoxin statistically significantly higher in a community adjacent to the composting facility during compost operations than in a non-exposed community?

1. must define “non-exposed”:
   a. a community located in an area that is always upwind from the facility?
   b. a community that is at a distance from the facility - (5-10 miles?)

II. What are you going to measure? Which material - dust, specific organisms? Keep your research question in mind - What is your purpose in collecting this information?

A. Materials released during yard-waste handling may include biological matter from the original yard waste or added bulking material:

1. plant material
2. wood dust

B. Organisms that are increased during the compost process, but occur to a lesser degree in untreated yard waste.

1. bacteria
2. thermophilic actinomycetes
3. *Aspergillus fumigatus*

III. What collection method are you going to use? Your choice of method to collect air samples depends on the material (dust, organisms, etc.) that you are studying and the detection/assay procedure that the laboratory will use to identify and quantify that material. Therefore this decision should be made in consultation with staff at the laboratory with which you will be working. Available options include:

A. Collection of airborne target microorganisms onto a membrane filter or into a liquid impinger. The air sampler is preceded by a cyclone or other device to separate larger and smaller particle size fractions, e.g., cutpoint at 10 µm (PM10) or 4 µm (non-respirable).

B. Collection of airborne microorganisms directly onto a growth medium for recovery of culturable bacteria and fungi. Dr. P. Millner, U.S. Department of Agriculture, recommends a multi-stage multiple-hole impactor and reporting of microorganism concentrations in non-respirable and respirable particle size fractions.

C. Collection of airborne material onto an adhesive surface for direct examination by light microscopy. This technique is useful for identifying pollen grains and identifiable fungal spores.

D. Collection of airborne material onto a coated glass slide for measuring optical density of collected material as an estimate of total suspended particles. The deposit on the slides also could be examined microscopically as described in III - C above.

IV. Where are you going to collect air samples? Air samples should be collected at several locations depending on the research question you are trying to answer. The following examples use the two research questions stated in section I of this outline.

A. Example 1 - Comparing levels of *Aspergillus fumigatus* at a landfill/composting site and at a worst-case neighboring community.

1. Take air samples at 2 representative locations near the perimeter of the yard-waste handling operation:
   a. at a site that is most consistently upwind of the operation
   b. at a site that is most consistently downwind of the operation
   c. if wind direction is routinely variable, consider setting up sampling stations at more than two sites or determine collection sites on basis of concurrent meteorological data (if available).
2. Take air samples at a representative worst-case location (i.e., a location likely to receive the highest exposure to target microorganisms originating from the yard-waste operation, such as a residential street near the site perimeter). The same community sampling location might be used for all sampling days and times.

B. Example 2 - Comparing levels of airborne organisms in a community or location adjacent to a compost facility to those in a community or location that is not exposed to compost facility-generated bioaerosols.

1. Take samples at a representative worst-case location, such as a residential street near the compost facility (preferably a downwind location from the facility). The same community site would be used for all sampling days and times.

2 Take samples at a representative best-case location, i.e., in a community or at a location that is likely to receive no or minimal exposure originating from the yard-waste operation. The same community site would be used for all sampling days and times.

V. When are you going to collect air samples? The following are minimal recommended collection times:

A. “Background” or “control” samples should be collected at all sampling locations on days or at times when no yard waste is delivered, processed or transported.

B. “Test” samples should be collected at all sampling locations on days and at times when yard waste is received, processed or transported.

C. A review of typical activity patterns at the yard-waste handling site will be needed to decide when samples should be collected to ensure measurement of air concentrations of target microorganisms during times of anticipated peak and minimal release.

D. At least some samples should be collected in summer, as bioaerosol levels associated with composting are routinely higher during this season.

VI. How many samples will you collect, over what period of time?

A. A sufficient number of samples should be collected to allow for adequate statistical evaluation of the data (consultation with a biostatistician is recommended). An appropriate number of quality control samples should be included.

B. The collection period should be sufficiently long to provide the information needed to address the research question, but as short as possible to facilitate decision-making regarding the yard-waste processing operation.

Appendix B

Laboratories for Bioaerosol Testing		
AEROBIOLOGY LABORATORY 11800 Sunrise Valley Dr., Suite 1200 Reston, VA 20191 (703) 648-0822 FAX: (703) 648-0319	**AEROTECH / KALMAR** 2020 W. Lone Cactus Dr. Phoenix, AZ 85027 (800) 651-4802 FAX (602) 780-7695	**AIR QUALITY SCIENCES, INC.** 1337 Capital Circle Marietta, GA 30067 (800) 789-0419 FAX (770) 933-0641
ALK INDOOR ALLERGEN ANALYSIS P.O. Box 291 Spring Mills, PA 16875 (800) 773-DUST FAX (814) 422-8424	**ANALYTICAL SERVICES, INC**. P.O. Box 515 130 Allen Brook Lane Williston, VT 05495 (800) 723-4432 FAX (802) 878-6765	**APPLIED MICROBIOLOGICAL SERVICES, INC.** 2625 Lime Ave, Signal Hill, CA 90806 (562) 595-7576 FAX (562) 595-6593
BIOTEST 66 Ford Road, #131 Denvil, NJ 07834 (800) 522-0090 FAX (973) 625-9454	**CLAYTON ENVIRONMENTAL CONSULTANTS, INC.** 5785 Corporate Ave, Suite 150 Cypress, CA 90630 (714) 229-4806 FAX (714) 229-4805	**CLAYTON ENVIRONMENTAL CONSULTANTS, INC.** 1252 Quarry Lane Pleasanton, CA 94566 (925) 426-2600 FAX (925) 426-0106
ENVIRO TEAM, INC. 1461 SW 12th Ave. #A Pompano Beach, FL 33069 (954) 786-8565 FAX (954) 943-5059	**ENVIRONMENTAL MICROBIOLOGY LABORATORY** 11746 Alps Way Escondido, CA 92026 (760) 749-7630 FAX (760) 749-7386 REP: Janet Gallup	**ENVIRONMENTAL SAFETY TECHNOLOGIES, INC.** 3550 Frankfort Ave. Louisville, KY 40207-2560 (502) 893-6080 (502) 893-6088
ENVIRONMENTAL TESTING ASSOCIATES 5290 Soledad Rd. San Diego, CA 92109 (619) 272-7747 (619) 272-7764 REP: Dan Baxter	**ENVIRONMENTAL TESTING & TECHNOLOGY** 1106 Second St., Suite 102 Encinitas, CA 92024 (800) 811-5991 (760) 436-5990 FAX (760) 436-9448	**FORENSIC ANALYTICAL** 3777 Depot Road, Suite 409 Hayward, CA 94545-2761 (510) 887-8828 FAX (510) 887-4218 Dr. Sharon Harney – Microbiology Laboratory Supervisor
HEALTH SCIENCE ASSOCIATES 10771 NoeI St. Los Alamitos, CA 90720 (714) 220-3922 FAX (714) 220-2081 REP: Don Bissong, Ph.D.	**IBT REFERENCE LAB** 10453 W 84th Terrace Lenexa, Ks 66214 (800) 637-0370 (913) 492-2224 FAX (913) 492-7145	**MICRO TEST LABORATORIES** 3701 J Street, Suite 207 Sacramento, CA 95816 (916) 452-9808 FAX (916) 452-5347 REP: Dale Walton

Laboratories for Bioaerosol Testing		
MICROBIOLOGY REFERENCE LABORATORY 10703 Progress Way Cypress, CA 90630 (800) 445-0185 (714) 220-9213	**MICROBIOLOGY SPECIALISTS, INC.** 8911 Interchange Drive Houston, TX 77054-2507 (713) 663-6888 FAX (713) 663-7722	**MYCOTECH BIOLOGICAL, INC.** Route 1, Box 182 Jewett, TX 75846-9718 (800) 272-3716 Tel/FAX (903) 626-4429
NELSON LABORATORIES, INC. 280 South Redwood Road Salt Lake City, UT 84123 (800) 272-2088, (801) 963-2600 FAX (801) 963-2630 REP: Dennis Ransom	**P & K MICROBIOLOGY SERVICES** 1950 Old Cuthbert Road, Unit L Cherry Hill, NJ 08034 (609) 427-4044 FAX (609) 427-0232	**PATHCON LABORATORIES** 270 Scientific Dr, Ste 3 Norcross, GA 30092 (770) 446-0540 FAX (770) 446-0610 REP: George Morris, Ph.D. or Brian Shelton
PURE EARTH ENVIRONMENTAL LAB, INC. 7184 N. Park Dr. Pennsauken, NJ 08110 (609) 486-1177 FAX: (609) 486-	**TRI / ENVIRONMENTAL INC.** 9063 Bee Caves Road Austin, TX 78733 (800) 880-8378	